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(54) **HIGH SPEED FLYWHEEL**

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CPC F16F 15/315; F16F 15/3156; Y02T 10/6204; Y02E 60/16; B60K 6/105
USPC 74/572.1, 572.2, 572.21, 572.11, 573.1, 74/573.11, 573.12, 573.13, 574.1–574.4, 74/433.5; 310/74; 464/180; 440/52; 903/960
IPC F16F 15/30,15/315
See application file for complete search history.

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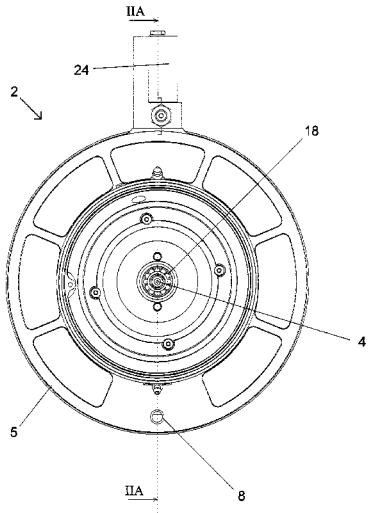
(57) **ABSTRACT**

A high speed flywheel system, including a flywheel mounted on a shaft, the flywheel being located within an evacuated chamber within a housing, wherein the chamber is sealed by seals including a cavity containing sealing fluid, wherein the seal cavity can be topped up with sealing fluid from a reservoir, the reservoir having an aperture open to the atmosphere for pressure equalization, the flywheel housing being mounted on the shaft via a bearing arrangement including at least one bearing situated externally to the chamber.

11 Claims, 11 Drawing Sheets



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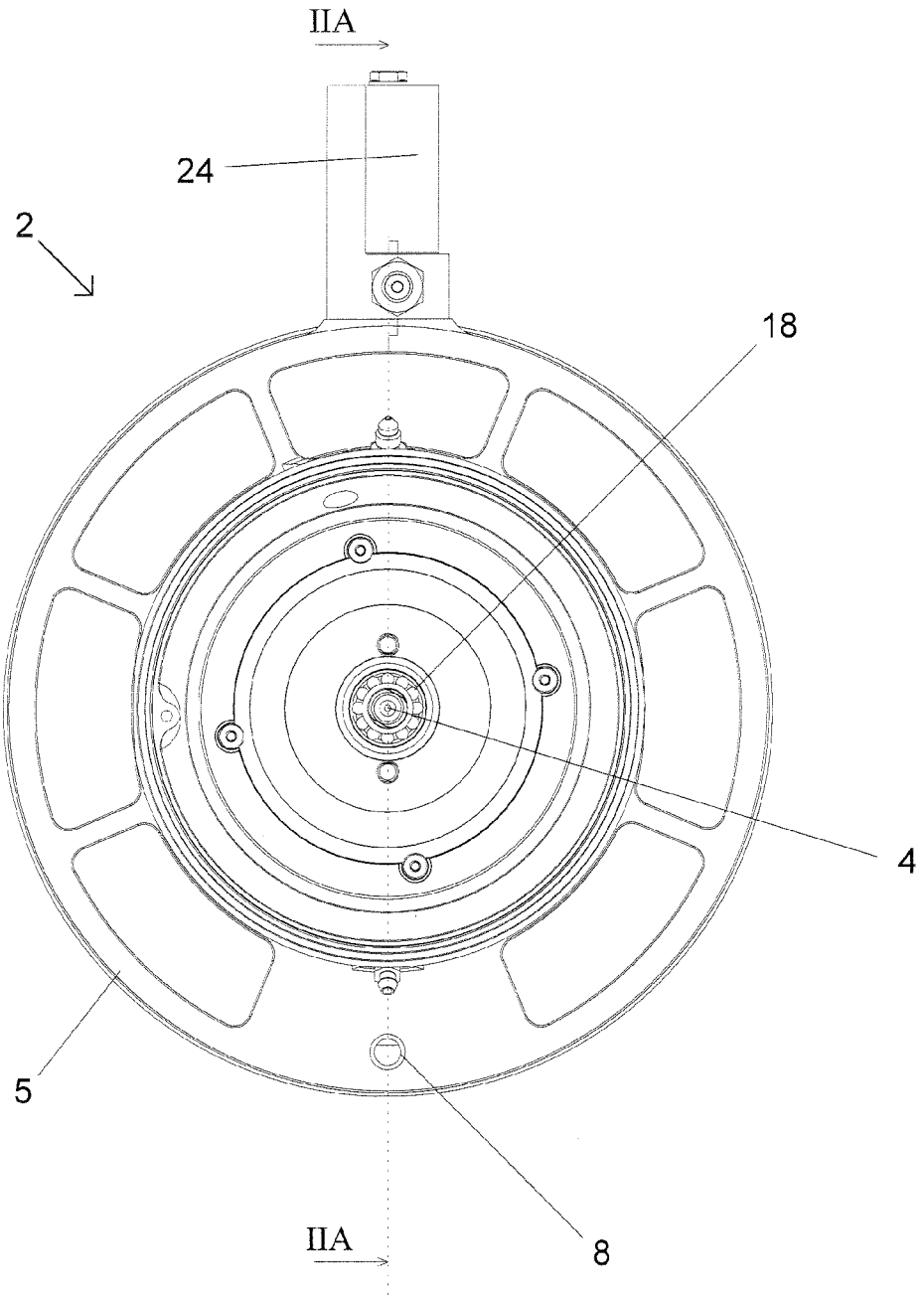

Fig. 1

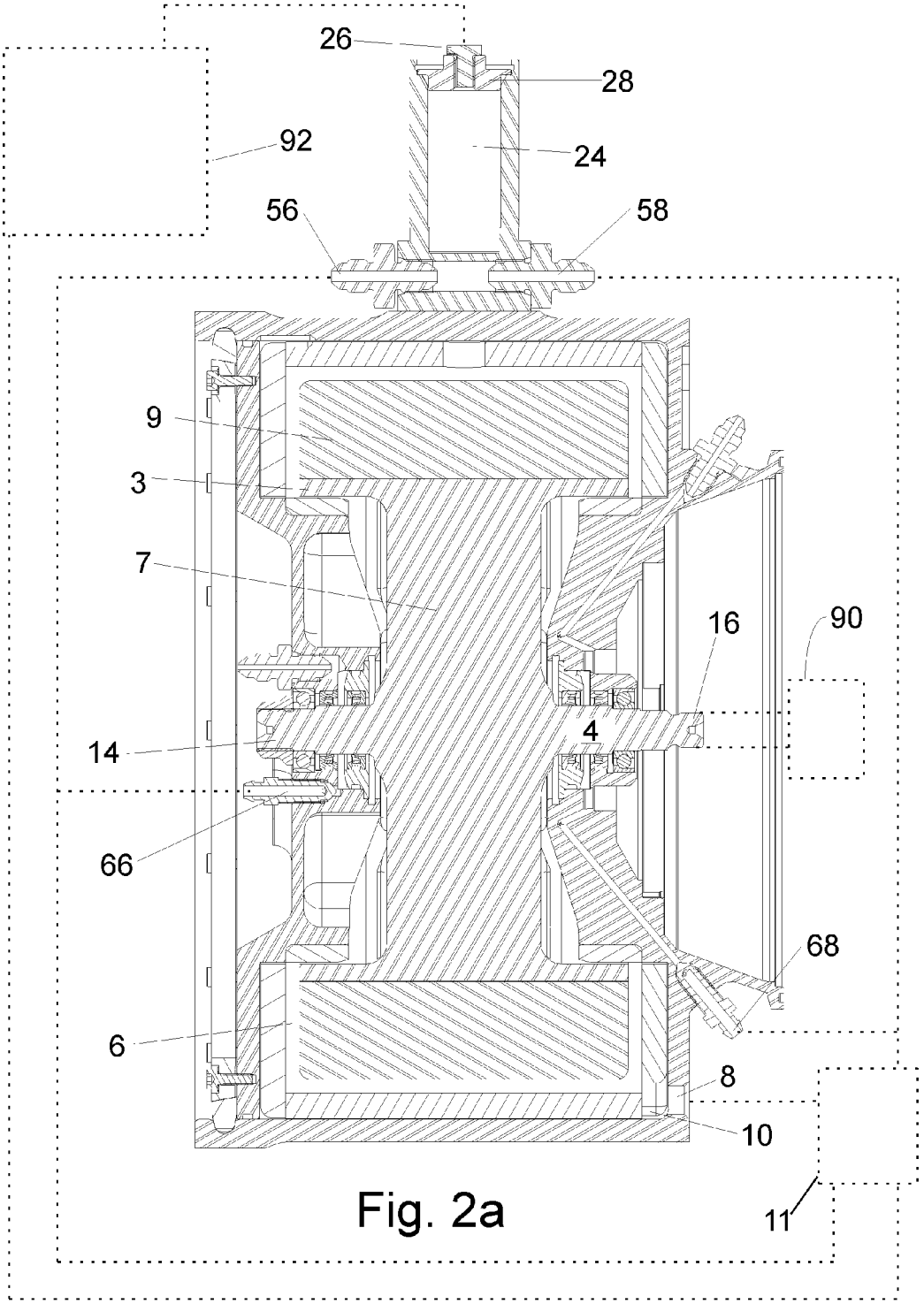

Fig. 2a

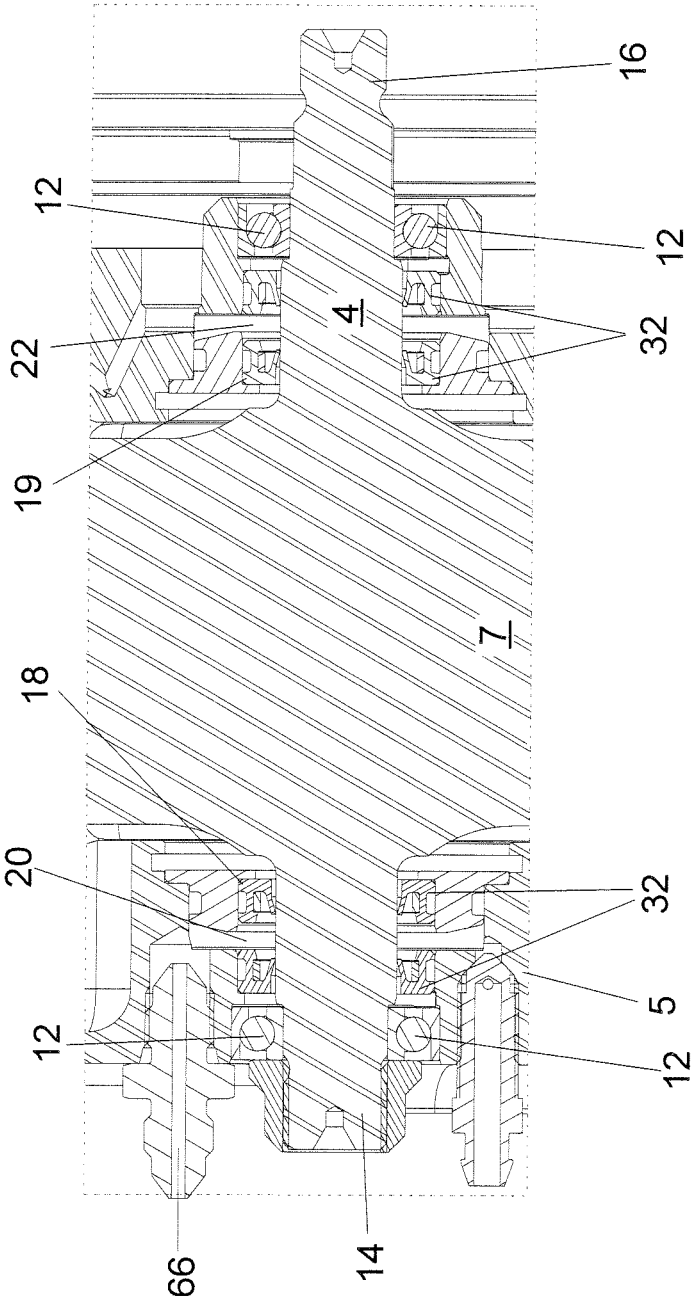

Fig. 2b

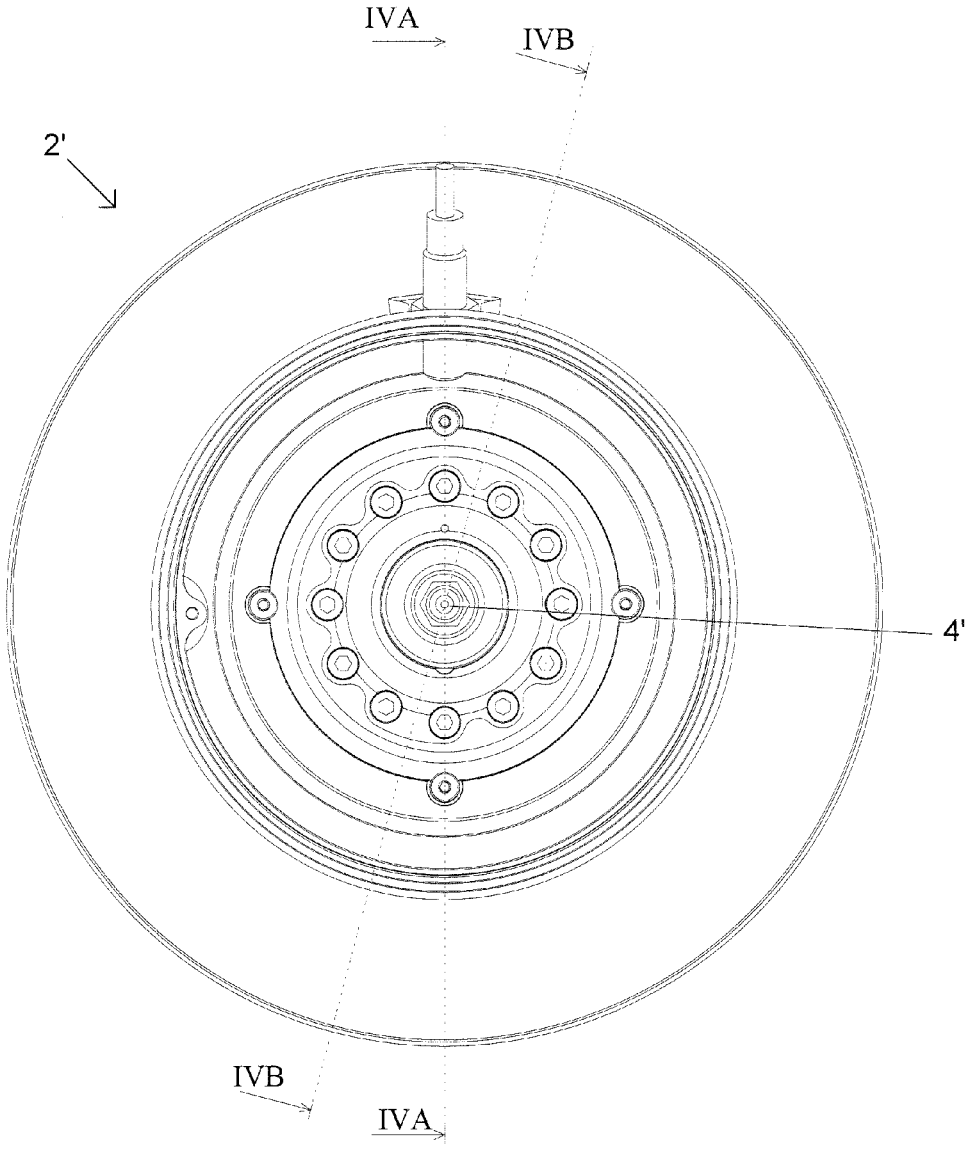

Fig. 3

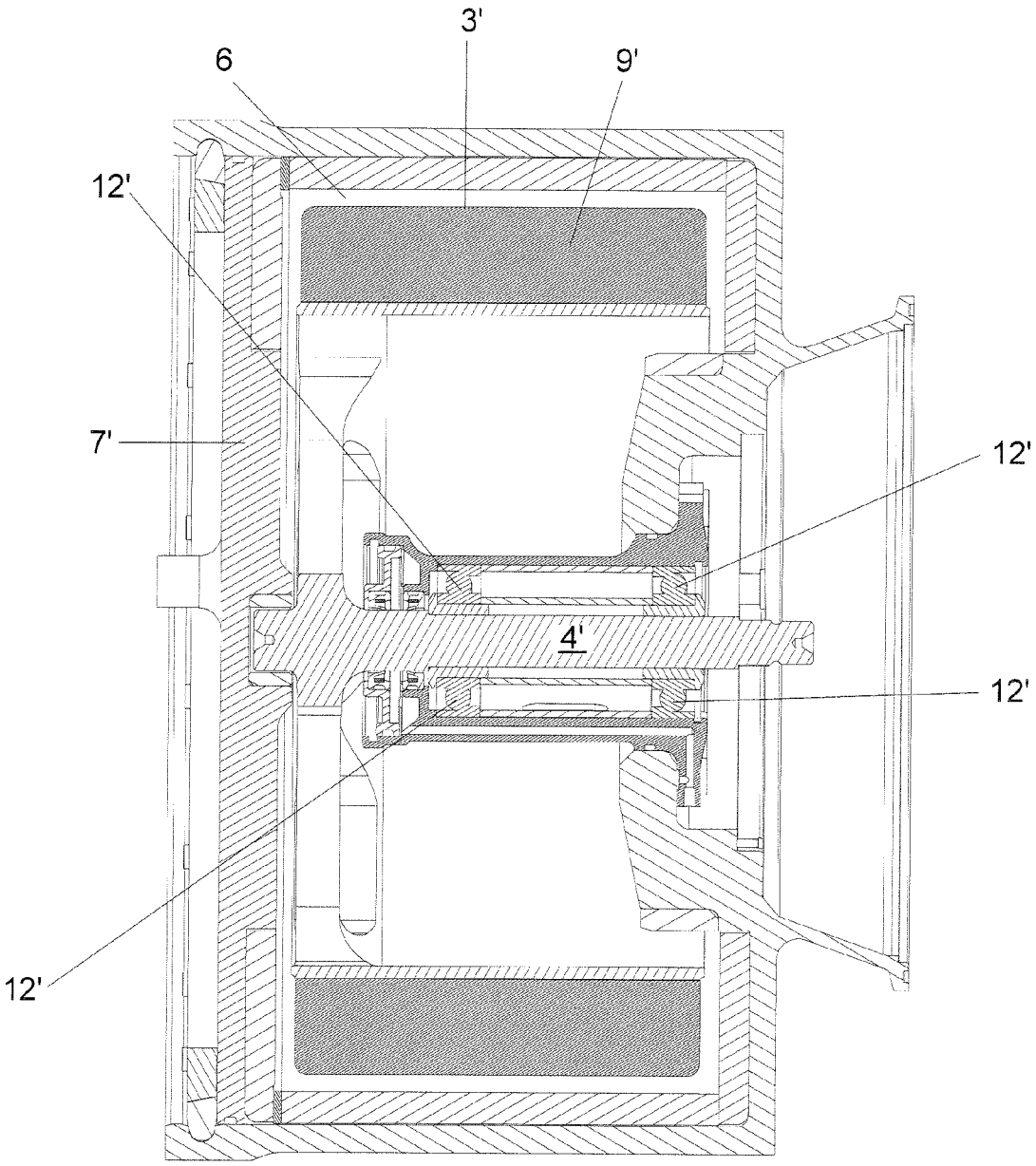

Fig. 4a

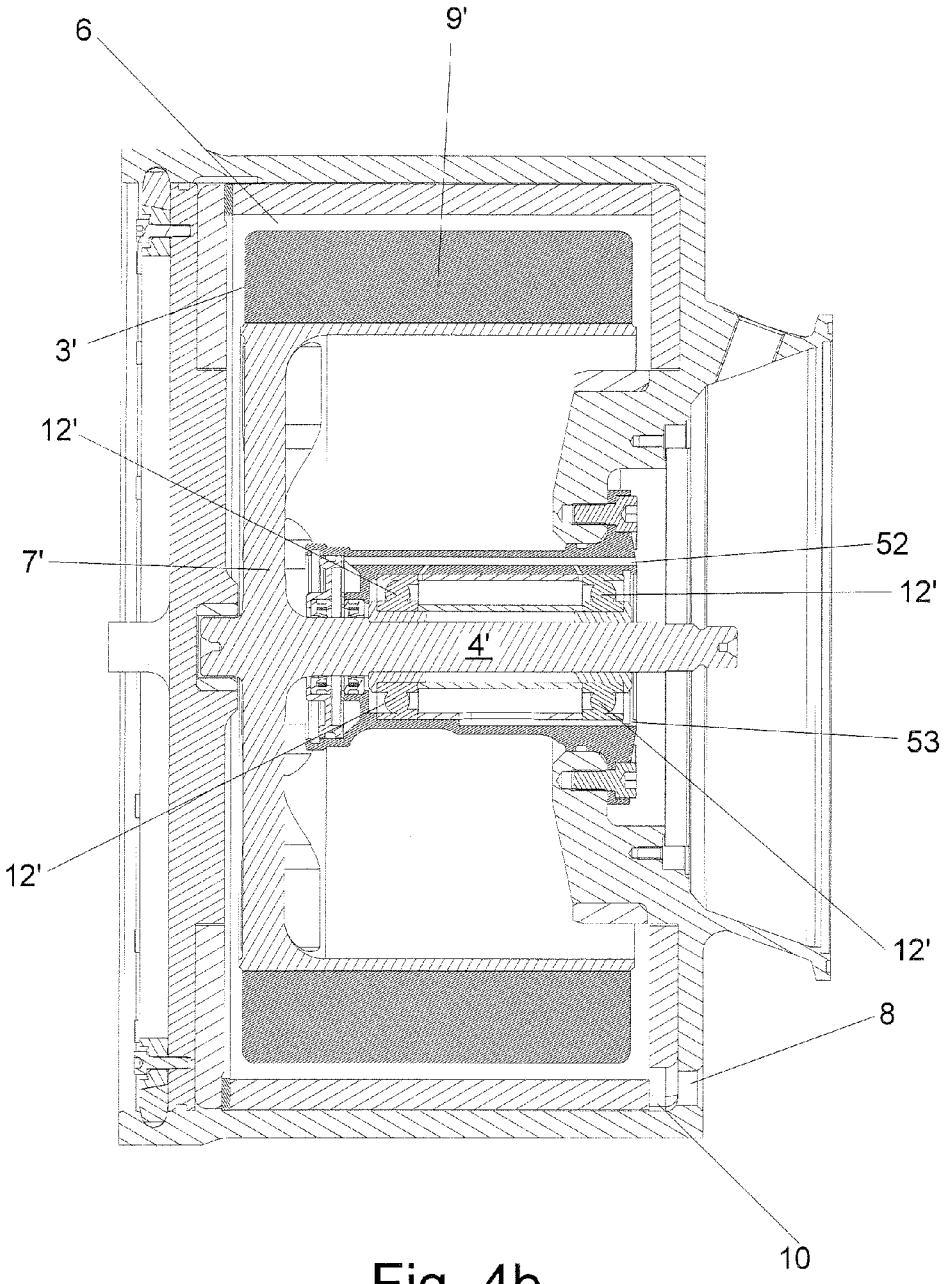

Fig. 4b

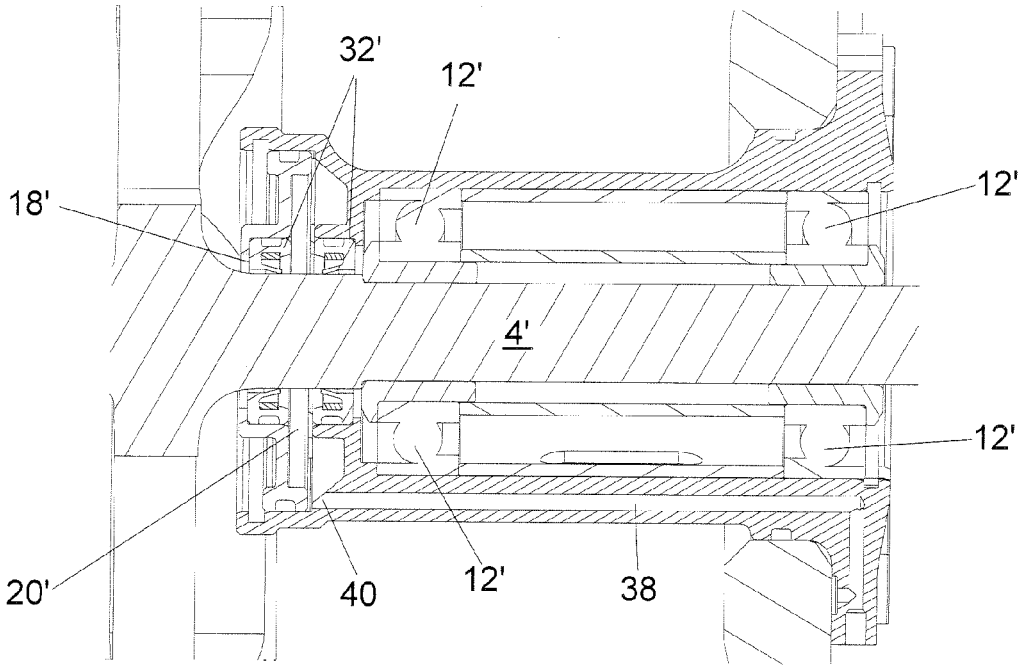

Fig. 4c

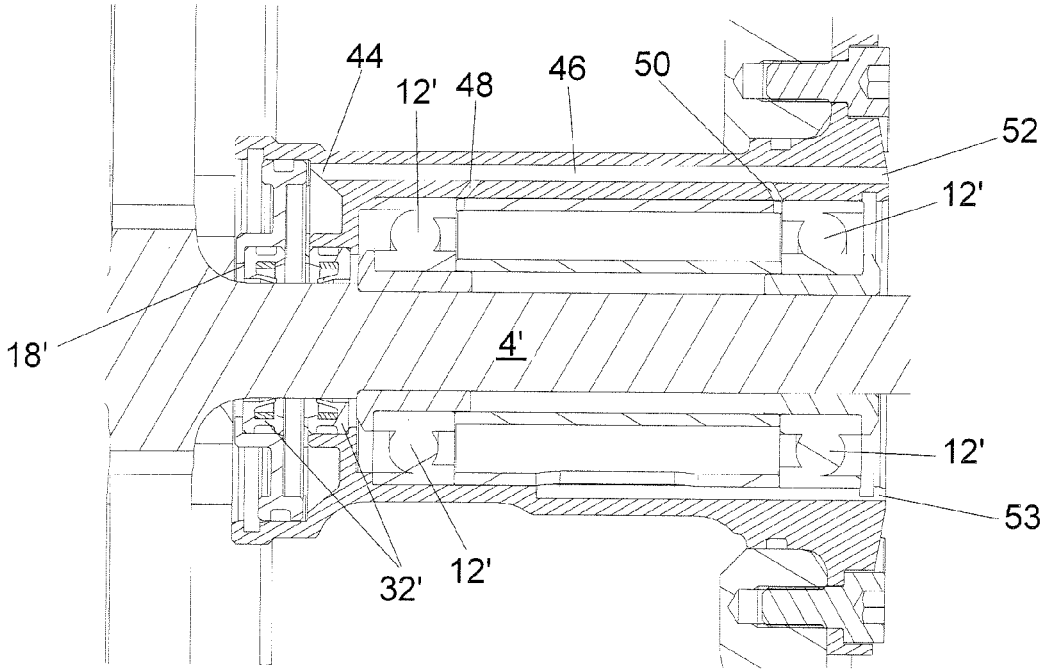

Fig. 4d

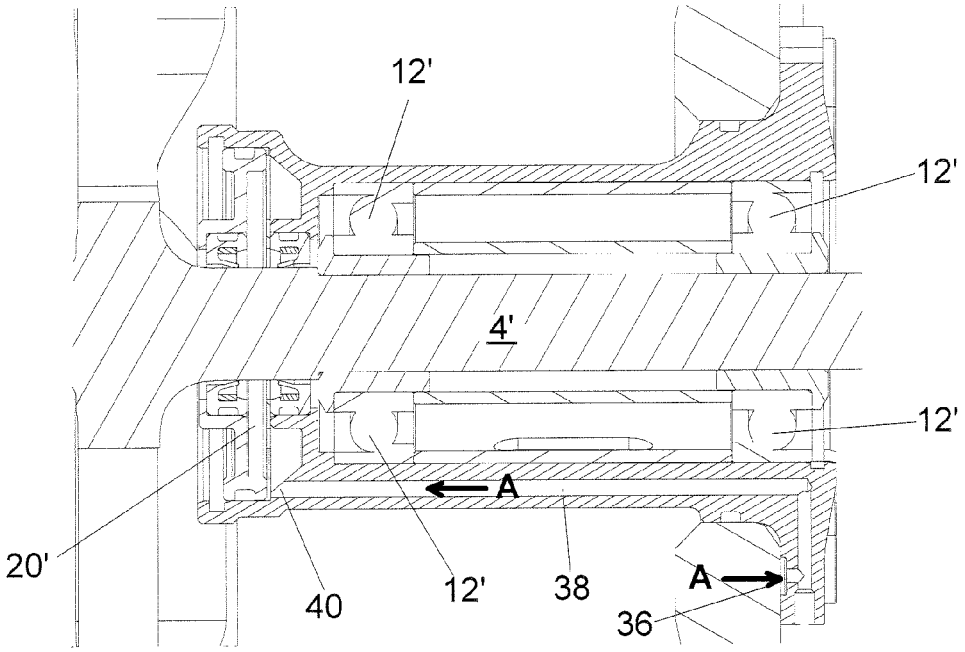

Fig. 4e

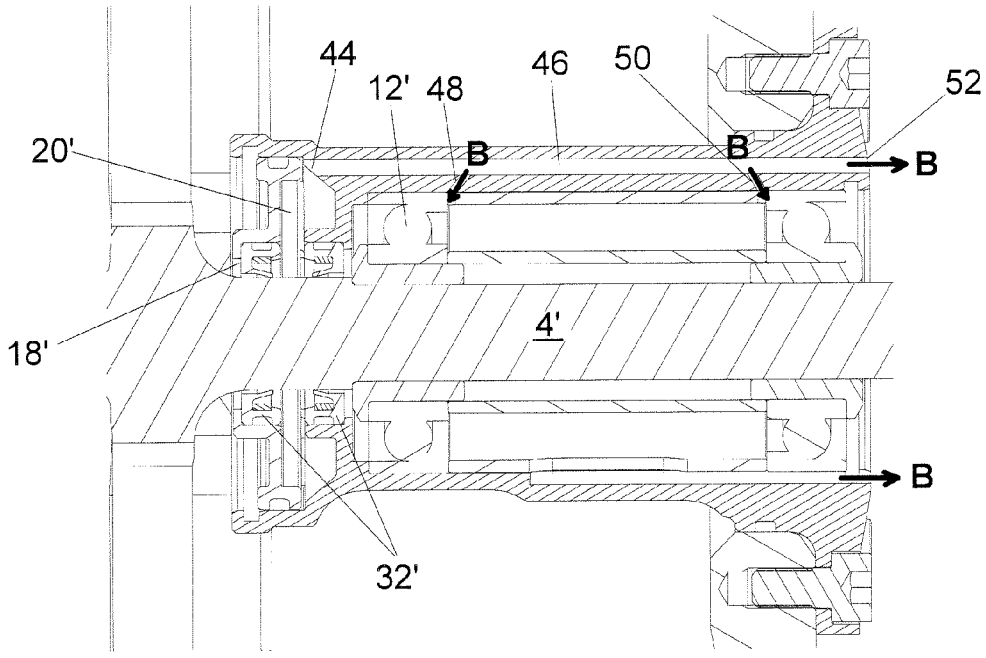

Fig. 4f

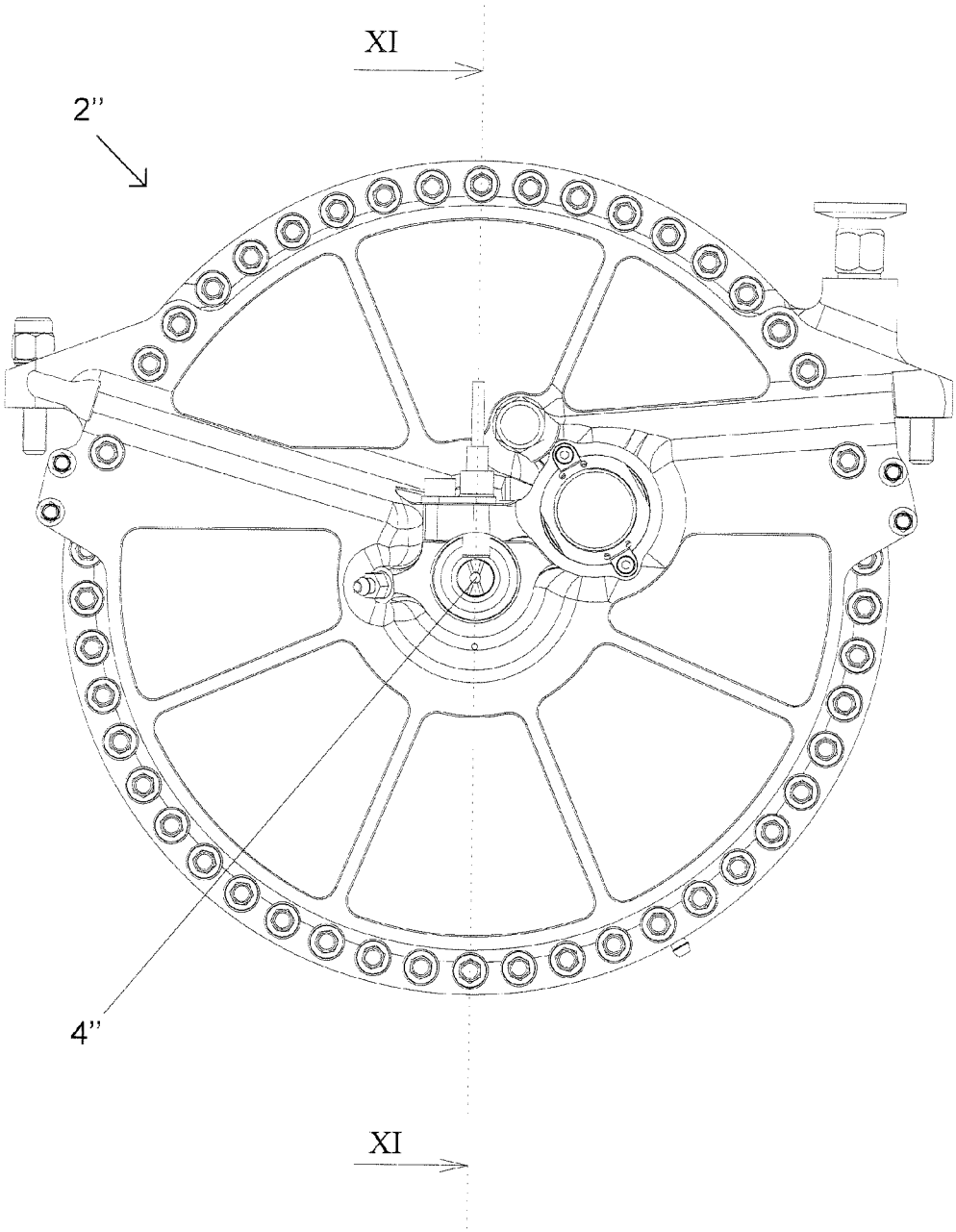

Fig. 5

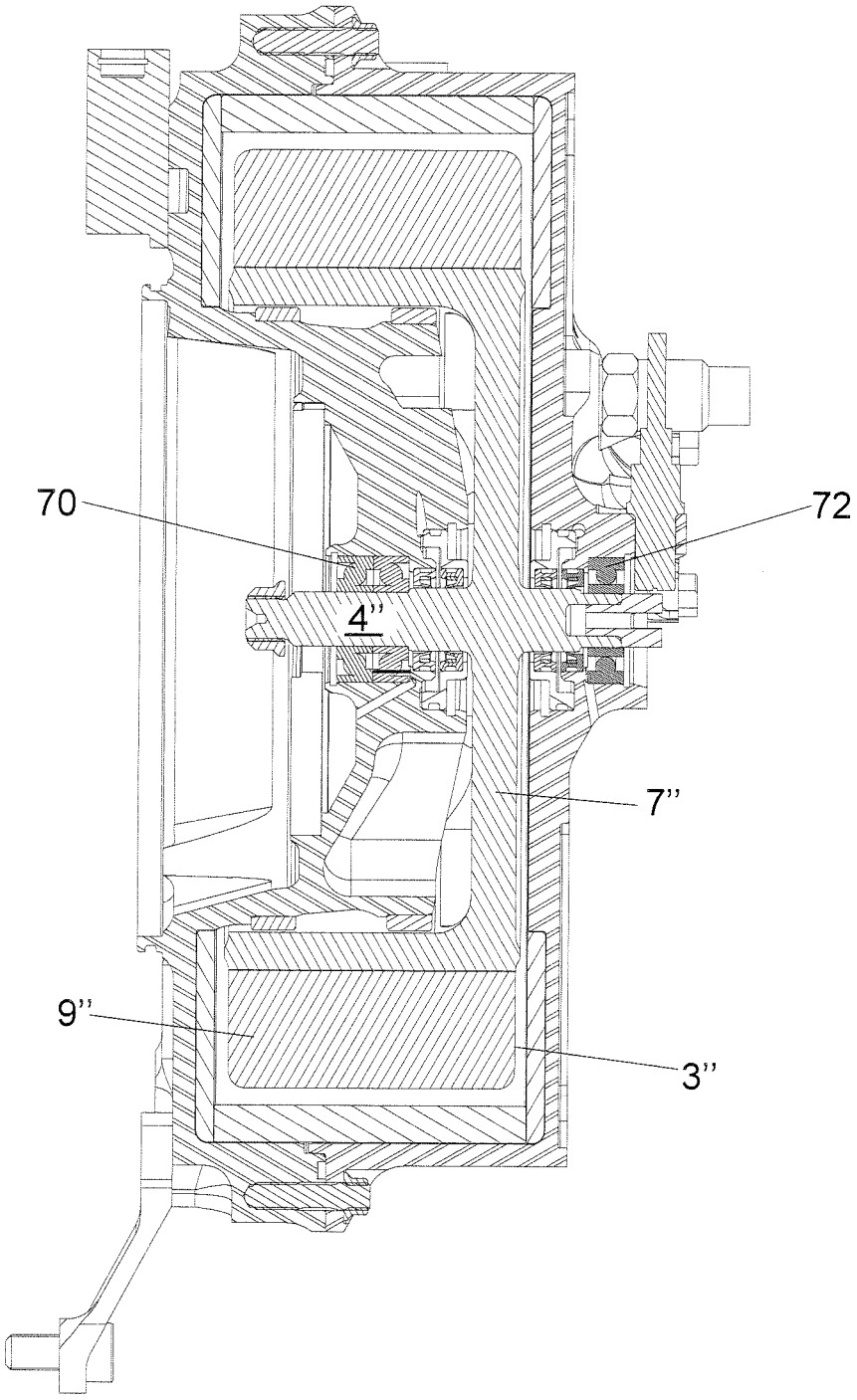

Fig. 6a

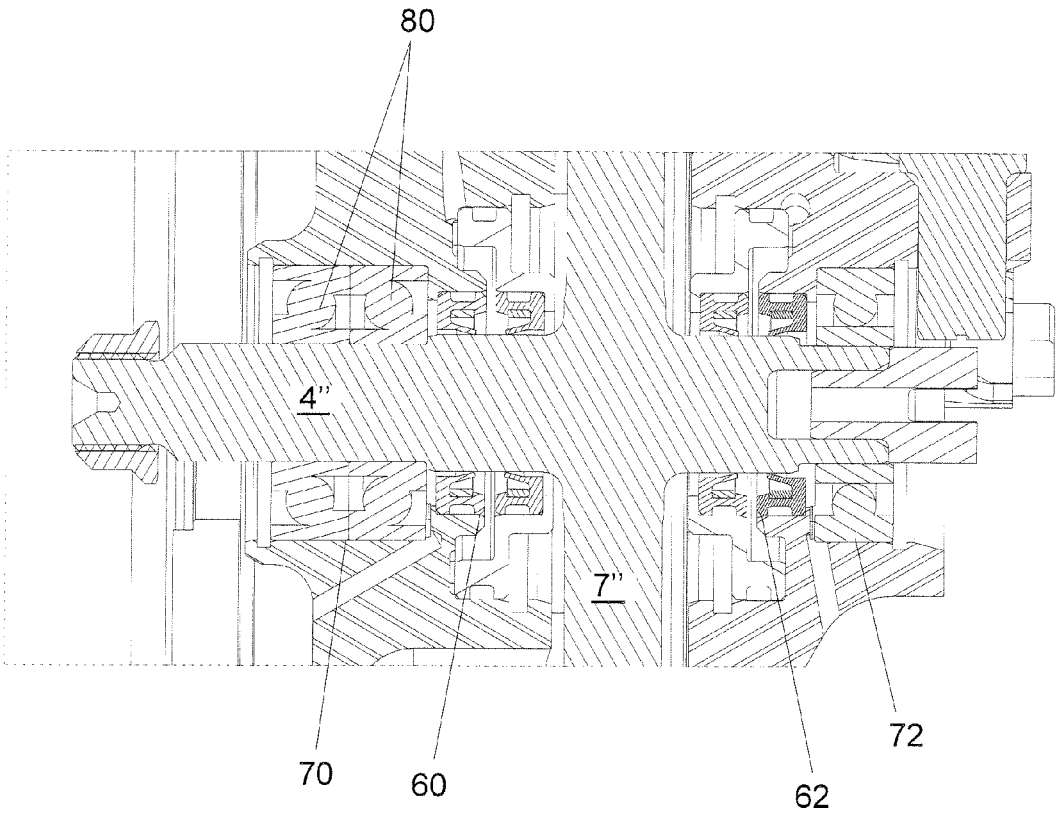

Fig. 6b

HIGH SPEED FLYWHEEL

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is the U.S. National Phase under 35 U.S.C. §371 of International Application No. PCT/GB2009/050909, filed Jul. 23, 2009, designating the United States and published in English on Mar. 11, 2010, as WO 2010/026401, which claims priority to United Kingdom Application No. 0816359.4, filed Sep. 8, 2008.

FIELD OF THE INVENTION

This invention relates to high speed flywheels, and particularly to bearings for high speed flywheels for use in vehicles.

The use of high speed flywheels in vehicles is known, for example, for braking energy storage and recovery systems, whereby kinetic energy is recovered on braking of the vehicle.

DESCRIPTION OF RELATED ART

Flywheels typically comprise a relatively heavy mass, mounted on a shaft and arranged to rotate with the shaft. High speed flywheels are usually contained in a chamber within a housing, a vacuum being applied to the chamber, in order to reduce energy losses caused by drag, and prevent the temperature of the flywheel from rising too high as a result of friction with surrounding air. A seal is provided between the housing and the shaft in order to allow a vacuum to be maintained within the chamber.

Bearings are provided to rotatably couple the housing to the shaft. Currently known bearings for high speed flywheels include high grade rolling element bearings, positioned between the seals and the flywheel, i.e. inside the vacuum sealed chamber containing the flywheel.

Problems associated with the above type of flywheel bearing include a restricted choice of bearing lubricant. The lubricant must be of a type which does not vaporise at the pressure of the evacuated flywheel chamber. It is also difficult to maintain the lubricant within the bearing without the use of a touching seal or lip seal; the use of such a seal is undesirable because makes it difficult to pump the chamber down to a vacuum, and because the lubricant is likely to leak during pump down.

Current flywheel seals may also include sliding pistons in the seal mechanism, which are exposed to sealing fluid on one side and to the atmosphere on the other side. The pistons are movable in accordance with the expansion of the sealing fluid as it becomes heated on operation of the flywheel, thereby maintaining the sealing fluid at atmospheric pressure and preventing excessive pressure building. Although such pistons are aimed at allowing equalisation of the pressure on each side of the piston, a small amount of friction between the piston seal and the piston housing prevents complete equalisation of the pressure on each side of the piston.

A flywheel seal is ideally filled with sealing fluid once for the life of the seal. The condition of the sealing fluid will deteriorate with time; small particles from the seals may wear off and contaminate the sealing fluid, or the fluid may start to degrade with temperature cycles. The life of the seal may be limited by the condition of the sealing fluid within it.

If leakage of sealing fluid into the evacuated chamber occurs as a result of wear of the seal, the sealing fluid must be replaced manually, therefore increasing maintenance requirements, and reducing service life of the seal.

SUMMARY OF THE INVENTION

It is an aim of the present invention to overcome or at least mitigate the above problems.

Accordingly the present invention provides a high speed flywheel as flywheel and a shaft, the flywheel being located within a chamber within a housing, wherein the chamber is evacuated and sealed by at least one seal comprising a cavity containing sealing fluid to an optimum level, the housing being mounted on the shaft via a bearing arrangement comprising at least one bearing situated externally to the chamber.

The location of the bearings outside the evacuated chamber in the present invention allows the bearings to be lubricated by any suitable fluid; it is not necessary to use a fluid which does not vaporise at the near-vacuum pressure of the evacuated chamber.

Therefore the most efficient conventional bearing lubricant can be chosen to provide that the bearings have a longer life than that of prior art embodiments. Accordingly, the permissible load ratings for the bearings are higher than those of prior art embodiments having bearings that are located inside the evacuated chamber, and the bearings can therefore be smaller, lighter, and of lower friction and cost.

A fluid reservoir may be provided for topping up the sealing fluid, for example if any fluid is caused to leak. The sealing reservoir can provide that any fluid that leaks from the seals due, for example, to wear incurred in service, can be automatically topped up. The service intervals and maintenance costs of the seals are therefore reduced.

The fluid reservoir may be open to the atmosphere. Pressure-balancing pistons required as used in certain prior art embodiments are therefore unnecessary, and therefore problems such as pressure imbalances caused by piston friction are eliminated.

The sealing fluid may be supplied via an opening near the bottom of the seal cavity, with a second opening being provided near the top of the seal cavity to allow fluid to escape, thereby allowing a constant through flow of fluid, hence extending service intervals and easing maintenance requirements due to lack of necessity for manual top-up of fluid. The flow of sealing fluid may also be directed past the flywheel bearings, in order to provide lubrication and cooling.

The sealing fluid reservoir may be topped up from a lubrication system of the flywheel drive mechanism.

Evacuation of the chamber prior to use of the flywheel is preferably via a vacuum port located on or near to the bottom of the chamber. The location of the vacuum port thereby allows for recovery of any sealing fluid which has wept past the seal, and re-use of the recovered sealing fluid.

Preferably an on-board pump is provided to scavenge, i.e. recover, any leaked fluid from the bottom of the evacuated chamber. The pump is preferably connected to the bottom of the evacuated chamber. The pump can initially scavenge any sealing fluid from the bottom of the chamber, and then top-up the vacuum level. The sealing fluid scavenged from the bottom of the chamber may then be returned to the fluid reservoir and re-used, providing cost and maintenance advantages.

When the sealing fluid reservoir has been topped up from a lubrication system for the flywheel drive mechanism, sealing fluid scavenged from the bottom of the chamber may be returned to the lubrication system.

In an alternative embodiment, a pair of angular contact bearings is positioned at one end of the shaft, with the seal on the flywheel side of the bearing arrangement. The other end

the shaft is supported by a bearing allowing axial displacement, the seal again being provided on the flywheel side of the bearing arrangement. This embodiment allows relative axial movement of the bearing arrangements at each end of the flywheel shaft. Such movement also compensates for different coefficients of thermal expansion of the flywheel shaft and vacuum chamber, and different working and non-working temperatures. Relative axial movement of the bearing arrangement also allows for deflection of the vacuum chamber due to a lower internal chamber pressure than the external environment pressure.

In a further alternative embodiment, the bearing arrangement comprises a cantilevered flywheel bearing arrangement. In this embodiment, the flywheel is mounted at one end of the flywheel shaft, and the bearings are located between the flywheel and the shaft. The seal is positioned on the flywheel side of the bearings. This arrangement provides an advantage that only one seal is required.

Part or all of the flywheel may be formed integrally with the shaft. For example, a web of the flywheel may be formed integrally with the shaft.

BRIEF DESCRIPTION OF THE DRAWINGS

An embodiment of the present invention will now be described by way of example and with reference to the accompanying drawings in which:

FIG. **1** is a front elevation of a flywheel in accordance with the present invention;

FIG. **2***a* is a cross-sectional view of the flywheel of FIG. **1** along the line IIA-IIA;

FIG. **2***b* is a partial cross-sectional view of the flywheel of FIG. **1** along the line IIB-IIB;

FIG. **3** is a front elevation of an alternative embodiment of flywheel in accordance with the present invention;

FIGS. **4***a* and **4***b* are cross-sectional views of the flywheel of FIG. **3** along the lines IVA-IVA and IVB-IVB respectively;

FIGS. **4***b* and **4***c* are partial cross-sectional views corresponding to FIGS. **4***a* and **4***b* respectively;

FIGS. **4***e* and **4***f* are partial cross-sectional views corresponding to FIGS. **4***c* and **4***d* respectively, illustrating the path of the sealing fluid;

FIG. **5** is a cross-sectional view of a further alternative embodiment of a flywheel in accordance with the present invention;

FIG. **6***a* is a cross-sectional view of the flywheel of FIG. **5** along the line VI-VI;

and

FIG. **6***b* is a partial cross-sectional view of the flywheel of FIG. **5** along the line VI-VI.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Referring to the embodiment of FIGS. **1**, **2***a* and **2***b*, the flywheel arrangement **2** comprises a flywheel **3** contained within a housing **5** mounted on a shaft **4**. The flywheel **3** comprises a web **7** and a rim **9**. The web **7** of the flywheel **3** is formed integrally with the shaft **4**.

The housing **5** contains a chamber **6** which has been evacuated by a vacuum pump **11**, via a vacuum port **8**. The housing **5** is mounted on the shaft **4** by rolling element bearings **12** which are provided near to each end **14**, **16** of the flywheel shaft **4**. Seal arrangements **18**, **19** are located against the shaft **4**, between each bearing **12** and the web **7** of the flywheel **3**. The seal arrangements **18**, **19** each comprise lip seals **32** and a first cavity **20** and a second cavity **22** containing sealing fluid (not shown).

A sealing fluid reservoir **24** is provided, whereby sealing fluid can be topped up from the sealing fluid reservoir **24** should any sealing fluid leak out of the seal arrangement cavities **20**, **22** and past the lip seals **32**. An opening **26** is provided at the top **28** of the sealing fluid reservoir **24** to provide that the sealing fluid reservoir **24** is open to the atmosphere, and thereby to ensure that the pressure of the sealing fluid in the sealing fluid reservoir **24** is equal to atmospheric pressure. Sealing fluid exits the reservoir **24** via first reservoir exit port ports **56** and second reservoir exit port **58**. The exit ports **56**, **58** are attached to a first seal cavity supply port **66** and a second seal cavity supply port **68** respectively, via tubing (not shown). Therefore the sealing fluid enters the first seal cavity **20** via the first seal cavity supply port **66**, and enters the second seal cavity **22** via the second seal cavity supply port **68**.

If leakage of sealing fluid into the chamber **6** does occur, the leaked sealing fluid can be recovered from the chamber **6** by the vacuum pump **11**, connected to vacuum port **8**. In this manner it will first recover any sealing fluid from the bottom **10** of the chamber **6**, and then automatically top-up the level of sealing fluid in the seal cavities **20**, **22**. Once the seal cavities **20**, **22** have been topped up, any further recovered sealing fluid is then returned to the sealing fluid reservoir **24**.

In the alternative embodiment of the present invention illustrated in FIGS. **3** to **4***f*, the flywheel system **2'** includes a cantilevered bearing arrangement. In this embodiment, the flywheel **3'** comprising rim **9'** and web **7'** is mounted at one end of the shaft **4'**, and rolling element bearings **12'** are located between the web **7'** of the flywheel **3'** and the shaft **4'**. A seal arrangement **18'**, comprising lip seals **32'** and seal cavity **20'**, is positioned on the flywheel side of the bearings **12'**. The flow path of the sealing fluid is illustrated in FIGS. **4***e* and **4***f*. As illustrated in FIG. **4***e* by the arrows 'A', the sealing fluid enters into a supply aperture **36**, and flows via an entry channel **38**, through an entry port **40** located near the bottom of seal cavity **20'**, and into the seal cavity **20'**. As illustrated in FIG. **4***f* by the arrows 'B', the fluid exits the cavity **20'** of the seal arrangement **18** via an exit port **44** located near the top of the seal cavity **20'**, and along an exit channel **46**. Exit channel **46** is provided with two secondary channels **48**, **50**, which allow some of the sealing fluid to be diverted to the bearings **12'** to provide lubrication and cooling. The remainder of the sealing fluid exits via the exit apertures **52** and **53**. This embodiment allows a constant flow of sealing fluid through the seal cavity **20'**.

In the embodiment of FIGS. **5** to **6***b*, the flywheel system **2"** includes a flywheel **3"** comprising a rim **9"** and a web **7"** first bearing arrangement **70** comprising a pair of angular contact bearings **80** are positioned near one end of the shaft **4**. A first seal arrangement **60** is provided between the web **7"** of the flywheel **3"** and the first bearing arrangement **70**. The other end the shaft **4** is supported by a second bearing arrangement **72** allowing axial displacement, and a second seal arrangement **62** is located between the web **7"** of the flywheel **3"** of the second bearing arrangement **72**.

In an alternative embodiment, the sealing fluid reservoir is topped up from a lubrication system **92** (FIG. **2***a*) for a flywheel drive mechanism **90** (FIG. **2***a*), and any sealing fluid recovered from the bottom of the chamber by the pump is returned to the lubrication system **92**.

What is claimed is:

1. A high speed flywheel system comprising a flywheel and a shaft, the flywheel being located within a chamber within a

housing, wherein the chamber is evacuated and sealed to the shaft by at least one seal arrangement comprising a cavity containing sealing fluid, the at least one seal arrangement further comprising seals for retaining the sealing fluid in the cavity, wherein the housing is mounted on the shaft via at least one bearing arrangement comprising at least one bearing situated externally to the evacuated chamber and externally to the cavity, the system further comprising a sealing fluid reservoir, a pump arrangement comprising an inlet in fluid communication with the chamber and an outlet in fluid communication with the sealing fluid reservoir, the pump arrangement configured both to recover sealing fluid from the chamber via a path, for re-use by the flywheel system, and to evacuate air from the chamber via the same path to produce a vacuum within the chamber, a first opening arranged to allow sealing fluid to be supplied to the cavity, and a second opening arranged to allow sealing fluid to escape from the cavity, whereby a constant flow of sealing fluid through the cavity of the at least one seal arrangement is enabled, and wherein the system is arranged to direct sealing fluid flowing through the cavity of the at least one seal arrangement to the at least one bearing arrangement.

2. A high speed flywheel system as claimed in claim **1** wherein the sealing fluid reservoir is open to the atmosphere.

3. A high speed flywheel system as claimed in claim **1** wherein the first opening is provided near to the base of the cavity of the at least one seal arrangement, and the second opening is provided near to the top of the cavity of the at least one seal arrangement.

4. A high speed flywheel system as claimed in claim **1** further comprising a flywheel drive mechanism and a lubrication system for the flywheel drive mechanism, wherein the reservoir of sealing fluid is topped up from the lubrication system for the flywheel drive mechanism.

5. A high speed flywheel system as claimed in claim **1** wherein the sealing fluid flowing through the cavity of the at least one seal arrangement is directed to and past the at least one bearing arrangement.

6. A high speed flywheel system as claimed in claim **1** wherein the inlet comprises a vacuum port.

7. A high speed flywheel system as claimed in claim **1** wherein sealing fluid recovered from the chamber by the pump is directed to the cavity of the at least one seal arrangement to top up the level of the sealing fluid within the cavity.

8. A high speed flywheel system as claimed in claim **1** further comprising a flywheel drive mechanism and a lubrication system for the flywheel drive mechanism, wherein the reservoir of sealing fluid is topped up from the lubrication system for the flywheel drive mechanism and sealing fluid recovered from the chamber is returned to the lubrication system of the flywheel drive mechanism.

9. A high speed flywheel system as claimed in claim **1** comprising a first bearing arrangement wherein the at least one bearing arrangement comprises a pair of angular contact bearings on the shaft on one side of a web of the flywheel, and a second bearing arrangement on the shaft on the other side of the web of the flywheel, wherein the second bearing arrangement is arranged so as to allow axial displacement of the bearing with respect to the shaft.

10. A high speed flywheel system as claimed in claim **1** wherein the at least one bearing arrangement comprises a cantilevered bearing arrangement located between the flywheel and the shaft.

11. A high speed flywheel system as claimed in claim **10** wherein the at least one seal arrangement has one seal arrangement.

* * * * *